

SHORT COMMUNICATION

Partial Carotid Occlusion as Treatment for Intracranial Internal Carotid Aneurysms

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THE treatment of intracranial aneurysms is still a controversial problem in neurosurgery. In those cases in which it is decided that surgery is indicated, a direct intracranial approach with clipping or ligating of the neck of the aneurysmal sac is generally considered to be the ideal treatment. There are, however, situations where this is not possible. In some of these cases the wall of the aneurysm is reinforced by plastic materials, a method pioneered in recent years by Selverstone.¹ A useful and commonly performed procedure for internal carotid aneurysms has been ligation of the common carotid artery in the neck. McKissock² considers carotid ligation to be the treatment of choice for aneurysms arising from the internal carotid artery at the origin of the posterior communicating artery.

CAROTID LIGATION

Carotid ligation has been performed in the belief that it results in a marked drop in intravascular pressure distal to ligation. Definite evidence of this was presented by Sweet, Sarnoff and Bakay.³ In their opinion, this procedure relieves the weakened vascular wall of the stress of rhythmic forces and may also promote the formation of healing clot in the aneurysmal sac. Black and German⁴ have discussed in detail the hemodynamic effects of carotid ligation. Follow-up studies on patients so treated have shown good results but details with respect to pressure readings distal to the occlusion, as determined by ophthalmodynamometry, are not available in all reported cases. Russell and Cranston⁵ noted reduction in ophthalmic pressures in recent cases of carotid occlusion. In a series of measurements on a patient after carotid ligation, they found that the ophthalmic pressures returned to normal within three months, presumably as a result of increased collateral supply. Lowe⁶ has shown that after carotid ligation or occlusion the distal pressures are restored to 70% or more of normal in long-term follow-up studies. A drop in intravascular pressure, though beneficial, does not appear to be essential for the curative effect of carotid ligation on the aneurysm.

Interruption of pulsatile flow appears to be a more important factor in preventing rupture of the aneurysm. Support for this statement is given

ABSTRACT

A study was undertaken to investigate the possibility of using partial carotid occlusion instead of complete carotid ligation for the treatment of intracranial internal carotid aneurysms with a view to avoiding such complications of the latter procedure as neurological deficit resulting from cerebral ischemia, and ascending thrombus formation. The beneficial effect of carotid ligation has been explained by the interruption of pulsatile flow which can cause rupture of an aneurysm by resonance phenomena. Studies on blood flow in the aorta in dogs, as well as in a human carotid artery in vivo and in vitro, showed that the same object could be achieved by the use of constriction by a Poppen clamp. This changed the pulsatile blood flow to a relatively non-pulsatile state with slight diminution in mean flow. Partial occlusion of the common carotid artery is recommended for those cases of intracranial aneurysm in which complete carotid occlusion would not likely be tolerated.

in recent work by the author⁷ on the mechanism of rupture of aneurysms. It was definitely shown, in aneurysm models inserted in an artificial circulatory system, that pulsatile flow caused rupture of aneurysms which remained intact with the same volume of non-pulsatile flow under the same head of pressure. Based on similar factors and a calculation of hemodynamic factors, the resonance theory of aneurysm rupture has been postulated.⁷ A resonance frequency is induced in the aneurysm sac by the pulsating blood, flowing through the vessel past the sac. This is a situation parallel to the well-known phenomenon in acoustics where a sound wave, travelling in a hollow tube, will produce resonance frequency in a sac arising from it. This is the basic principle of many musical instruments, such as a whistle. If the frequency of oscillations in the carotid artery synchronizes with the resonance frequency of the aneurysm coming off this vessel, a maximum amplitude of response will be produced, leading to a sudden rise in tension in the aneurysmal sac which results in rupture. This is likely to happen under certain circumstances;

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among these, the size of the aneurysm is a critical factor. Changes in intravascular pressure are of no importance unless they affect the size of the sac. This resonance phenomenon is interrupted by carotid ligation because pulsations transmitted through a static or slowly moving column cannot induce it.

COMPLICATIONS OF CAROTID LIGATION AND MODIFICATIONS OF TECHNIQUE

All patients do not tolerate carotid ligation, and a number of complications due to ischemia have resulted, varying from neurological deficit to death. In an attempt to overcome these difficulties, the procedure of gradual occlusion of the carotid artery

studied the effect on blood flow of reduction of the diameter of canine carotid arteries *in vitro* as well as *in vivo*. Reduction of carotid diameter was achieved by extraluminal as well as intraluminal devices, and blood flow was measured by an electromagnetic flowmeter without opening the vessel. The lumen of an artery with a diameter of 5 mm. could thus be reduced by 40% without any reduction in blood flow; reduction of the diameter by 70% produced only 49% reduction in flow.

Cannon *et al.*¹¹ reported the reduction of the cross-sectional area of an artery with a diameter 8 mm. by 94% without any reduction in mean flow. Reduction of cross-sectional area by 99% reduced

TABLE I.—PRESSURE AND FLOW RECORDINGS*IN DOG AORTAS WITH POPPEN CLAMP CONSTRICTION DOWN TO 2.5 MM.

Dog number	Blood flow in cc./min.		Pulsations in millivolts		Systolic blood pressures (mm. Hg)			
	Before constriction	After constriction (% of original)	Before constriction	After constriction (% of original)	Before constriction		After constriction	
					Proximal	Distal	Proximal	Distal
1	410	377 (92.0%)	8.0	1.0 (12.5%)	120	110	130	60
2	312	290 (93.5%)	7.0	0.7 (10.0%)	115	100	125	50
3	240*	200 (83.3%)	6.6	1.0 (16.0%)	80	75	90	60
4	400	382 (95.0%)	7.8	0.8 (10.3%)	120	115	125	80
5	384	384 (91.0%)	8.5	0.8 (9.4%)	100	95	110	55
6	432	398 (92.5%)	8.0	0.8 (10.0%)	115	110	120	60

*This dog was under hypothermia.

was introduced, using Poppen and Selverstone clamps. One of these clamps, or some modification thereof, is applied at the time of surgery and the clamp is left open. Gradual narrowing of the clamp over a number of days is carried out in the post-operative period, with the object of promoting collateral circulation before complete closure. Some of the patients do not tolerate this procedure, and the clamp has to be removed without occluding the vessel.

Another complication of carotid ligation is ascending thrombus formation distal to the occlusion. To obviate this, Smith⁸ advocated the procedure of differential carotid ligation, in which the external carotid is ligated distal to the origin of the superior thyroid artery. The common carotid is then gradually narrowed in the usual manner by a Selverstone clamp. The object of this procedure is to promote sufficient collateral blood flow through the superior thyroid artery to prevent ascending thrombus formation. In some cases, however, there is reversal of blood flow following common carotid ligation; that is, the blood flows from the internal to the external carotid.⁹ In such cases, the beneficial effect of carotid ligation is lost because the pulsating blood still goes past the aneurysm. In view of these problems, the author investigated the possibility of using partial carotid occlusion instead of complete ligation as treatment.

EFFECT OF PARTIAL OCCLUSION ON BLOOD FLOW IN THE CAROTID ARTERY

The classical studies on this subject were performed by Mann *et al.*¹⁰ in 1938. These workers

the flow to 70%, and further reduction in the arterial lumen produced marked reduction in blood flow. These studies were carried out *in vitro* and repeated *in vivo* on dogs' aortas, and comparable results were obtained. Using an electromagnetic flowmeter, Cannon noted that the pulsations diminished before any change in the mean flow was evident. However, he did not pursue this point any further.

It is difficult to establish any hard-and-fast rule regarding the relation of lumen size to blood flow through it. Many variables are involved and it is difficult to compare the results of various authors using different methods. The present work was started with the objects of determining the degree of constriction needed to eliminate pulsations within an artery without producing a marked diminution of blood flow through it, and also the best method of achieving such a constriction.

EXPERIMENTAL WORK

The studies were done on a series of six dogs of an average weight of 10 kg. They were anesthetized with intravenous pentobarbital (Nembutal) and connected to mechanical respirators. In each case an extensive left thoracotomy was done and the thoracic aorta was exposed in its entire extent, carefully dissected, and all branches were ligated. The diameter of the aorta in the mid-thoracic region was approximately 8 mm., which is about the diameter of the adult human common carotid artery. Proximal blood pressure was measured by a cannula placed in the arch of aorta *via* the left common carotid artery. The distal pressure was

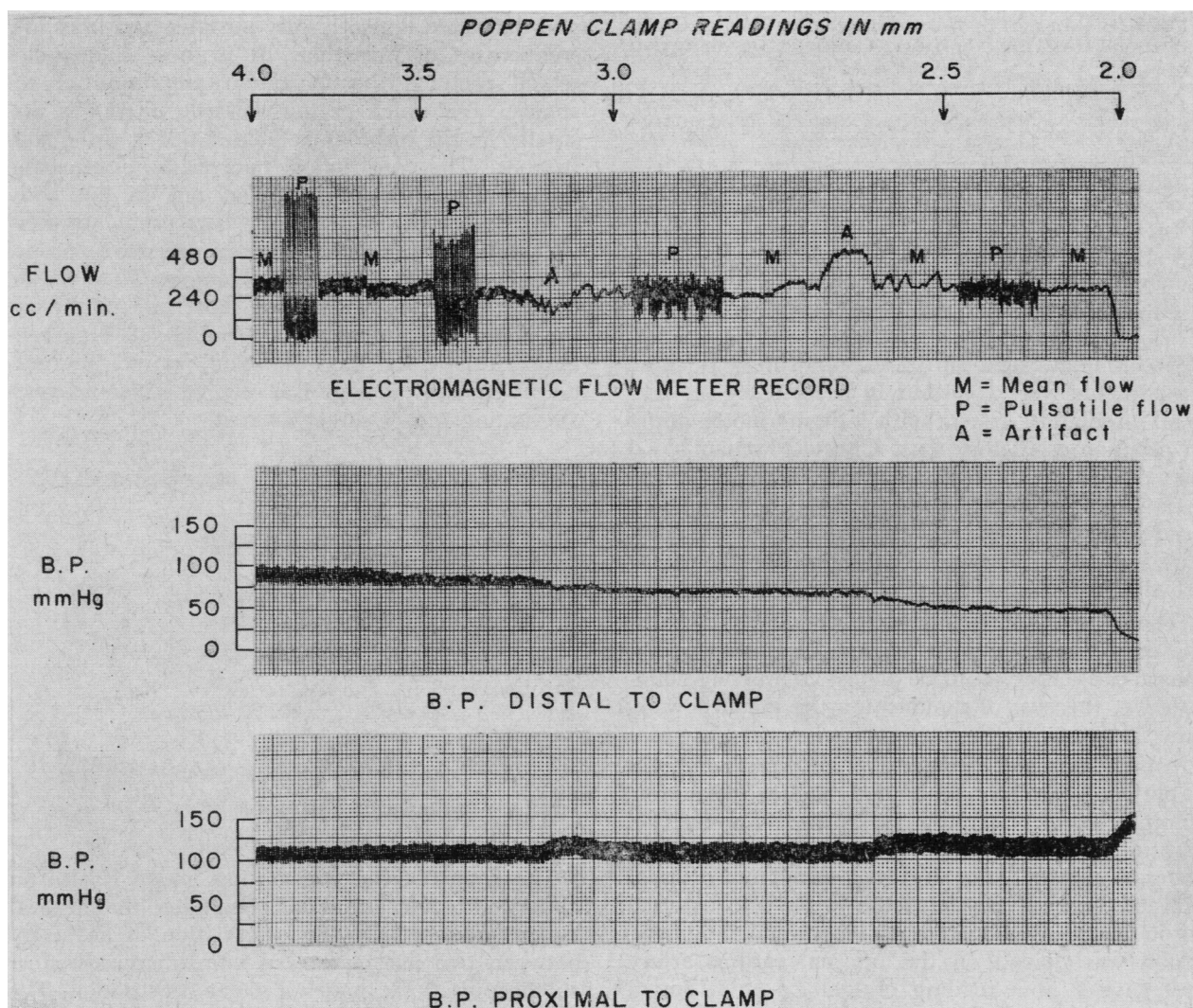


Fig. 1.—Effect of constriction by Poppen clamp on thoracic aorta of dog No. 2 in Table I.

measured by a cannula placed above the bifurcation of the aorta *via* the left femoral artery. Blood flow was measured by an electromagnetic flow probe placed around the lower part of the thoracic aorta. To achieve constriction, a Poppen clamp was applied to the thoracic aorta four inches away from the flow probe. The pressures and flow measurements were recorded simultaneously on a multi-channel Sanborn recorder. After the termination of the experiments the dogs were sacrificed.

The pressure and flow recordings are shown in Table I. Before starting constriction, the Poppen clamp was applied around the aorta, and when these were fully open a reading of 8 mm. was obtained. Constriction was increased by 0.5 mm. at each stage and all the recordings were repeated. No changes were noted in any of the dogs until the 4 mm. mark. As an example of changes subsequent to that, the recording of dog No. 2 is shown in Fig. 1. Narrowing of the clamp to the 3.5 mm. mark produced a decrease in the amplitude of pulsations (also recorded by the flow meter) without affecting the mean flow. The most extreme

effect was seen at the 2.5 mm. mark, where the amplitude of pulsation was 10% of that at the 4 mm. mark (or at the 8 mm. mark). Further constriction resulted in a marked drop in mean flow until at the 2 mm. mark there was no demonstrable flow. At this point the aorta was completely occluded because the thickness of both walls of the compressed aorta was exactly 2 mm. In this recording, it is also noted that the proximal blood pressure is higher than the distal. This is within the normal range of pressure gradient along the length of the aorta. The drop in the distal pressure occurs much earlier than the rise of proximal pressure. Also the drop in distal pressure is more than the rise of proximal pressure. This is the case in all the dogs shown in Table I. It is also shown that, even with constriction to the 2.5 mm. mark, the blood flow is maintained at above 90% of pre-constriction levels except in the case of dog No. 2 which was under hypothermia and had low blood pressure. The diminution in pulsation is the most striking feature. This diminution of pulsation is out of proportion to the drop in either the blood flow or the distal blood pressure.

TABLE II.—EFFECT OF CONSTRICTION WITH POPPEN CLAMP ON BLOOD FLOW THROUGH HUMAN COMMON CAROTID ARTERY (*in vitro*)

Clamp mark in mm.	Mean blood flow in c.c./min.	Pulsations in millivolts	Distal blood pressure in mm. Hg
8 (fully open)....	240	8.0	120
5	240 (100)*	8.0 (100)	120
4	228 (95.5)	6.0 (75)	110
3	204 (83.5)	1.0 (12.5)	95
2.5	180 (75)	0.2 (0.025)	70
2 (fully closed)...			

*The figures in parentheses are percentages.

To eliminate some of the variables in dogs, these experiments were repeated *in vitro*, using an artificial circulatory system with a Sigma motor pump to produce oscillatory flow. Citrated human blood was circulated through a human common carotid artery removed at autopsy, a Poppen clamp was used for constriction and the proximal blood pressure was kept constant at 120 mm. Hg. The results are shown in Table II.

These results are somewhat similar to those of the dog experiments. In addition it is shown that the pulsatile flow could be almost completely eliminated at the cost of diminishing the mean flow by only 25%.

An attempt was made to verify these results in a patient who was scheduled to have complete common carotid ligation for intracranial internal carotid aneurysm. Under local anesthesia the left common carotid artery and its internal and external divisions were exposed in the neck. The external carotid artery was ligated. An electromagnetic flow-probe was placed on the internal carotid artery and gave a flow reading of 290 c.c./min. and a pulsation of 4.8 millivolts. The intravascular pressure in the internal carotid artery was 115 mm. Hg, whereas the systemic pressure taken by auscultation over the arm was 120 mm. Hg. A Poppen clamp was applied to the common carotid artery and gradually narrowed. Because of certain limitations and technical difficulties, complete recordings could not be obtained, but it was noted that at the 3 mm. mark the flow in the internal carotid artery dropped to 218 c.c. (72%) and there was no recordable pulsation. The pressure in the lumen of the internal carotid artery at this stage was 45 mm. Hg. Complete occlusion of the common carotid artery was achieved at the 2.5 mm. mark, and this led to the drop of internal carotid pressure to 35 mm. Hg. The clamp was eventually removed and replaced by a completely occluding band around the common carotid artery.

DISCUSSION

The object of these experiments was to show that, by the use of a suitable constricting device on a vessel, it is possible to change pulsatile flow to a non-pulsatile state while maintaining a significant proportion of the mean flow. This result is explained by the fact that a jet coming out of a constricted

and deformed lumen is very unstable and loses low frequencies of pulsations. It is these frequencies which produce the maximum amplitude of response; also much of the pulsatile energy is dissipated in the turbulence created distal to the constriction. The constriction, in a way, performs the same function that is carried out in the body normally by small arterioles, where oscillatory flow is dissipated into kinetic energy needed to propel the blood through narrow channels. To illustrate the action of constriction on flow, one might use the analogy of smooth flow coming out of a container into which fluid is being poured intermittently. Another analogy is a rectifier which converts alternating into a direct current.

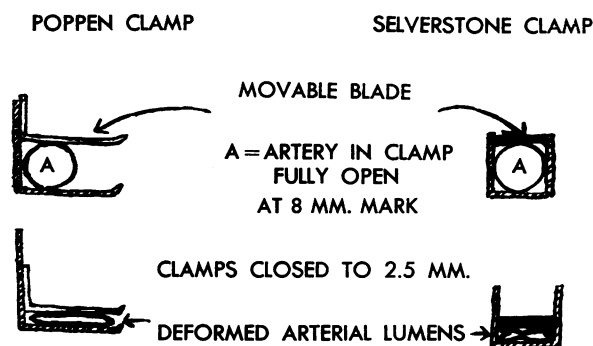


Fig. 2.—Diagrammatic comparison of modes of actions of Poppen and Selverstone clamps.

The shape of the constricting lumen is also an important factor, and it has been noted that an oval lumen produced by the constriction of an artery between two flat plates has more damping effect on the pulsations than a circular constriction. The Selverstone clamp gave very inconsistent results, and the explanation for this is clear in Fig. 2. Owing to limited space, the artery in a Selverstone clamp becomes distorted, whereas with a Poppen clamp it is flattened out and stretched in a transverse diameter. Thus, with a Poppen clamp, there is much less diminution in cross-sectional area than with a Selverstone clamp. The efficiency of a Poppen clamp shows that the flattening of the lumen of the vessel is a more important factor in causing the damping of pulsations than the diminution of cross-sectional area.

Partial Carotid Occlusion as Treatment for Internal Carotid Aneurysms

On the basis of the experimental evidence presented, partial carotid occlusion should be considered as treatment for internal carotid aneurysms which are not operable by direct approach and where carotid ligation is not tolerated by the patient. Since the actual measurement of the constriction is not important, a special clamp need not be used. A tantalum band, 2 to 3 mm. wide and 3 to 4 cm. long can be bent in the middle, and the common carotid can be constricted between its two limbs. The ends can be twisted together to prevent

slipping of the band from the artery. This band can be anchored to the artery by a silk suture passing through the adventitia of the artery. Tantalum bands are used by the author for the complete ligation of carotid arteries and have replaced the silk ligatures. This is based on the work of Reid,¹² who produced definite evidence that ligation of a large artery with a thread can damage intima and lead to aneurysm formation at the site of ligature. It is of interest to note here that in 1954 Gross and Holzman¹³ reported a case in which they attempted to ligate the common carotid artery in the neck in the treatment of an intracranial internal carotid aneurysm. Because the patient would not tolerate complete ligation, they left the artery partially ligated. They estimated that the lumen was reduced to about one-fourth of original size. No studies of blood flow or pressures were made. The patient improved following this procedure. They intended to complete the procedure of ligation at a second stage, but two months later the patient presented with an aneurysm at the site of ligation which was excised and was considered to have resulted from damage to the intima.

An uncommon sequel of this procedure is post-stenotic dilatation; the mechanism of its production has been discussed in detail by Holman.¹⁴ To prevent such an occurrence, the site of constriction and the vessel for a distance of 3 cm. distal to it should be reinforced by plastic coating.¹

An electromagnetic flowmeter is essential during this procedure in order to provide a guide to the degree of constriction required to cut off the pulsatile flow. The external carotid artery should be ligated to prevent reversal of flow, and flow-measurements should be made on the internal carotid artery.

This procedure can achieve the same results as complete carotid ligation. By changing pulsatile flow to non-pulsatile flow, it protects the aneurysm wall against the direct effect of pulsation as well as against resonance phenomenon which may cause rupture. A smooth flow past an aneurysmal sac produces only minimal hemodynamic disturbances, in contrast to the pulsatile flow which produces a marked whorling phenomenon in the sac. This has been shown in experiments on aneurysm models.⁷

Definite evidence has been presented both from animal experiments and human cases to show that partial occlusion can cause a pressure drop distally, although this is less than the drop which occurs after complete occlusion of a vessel.

The advantages of partial occlusion over complete occlusion are: It does not deprive the brain of blood supply to the same degree as complete carotid ligation. Its use can be extended to patients who do not tolerate complete carotid ligation. Furthermore, by maintaining the blood flow through the internal carotid, it lessens the chance of ascending thrombus formation. Follow-up angiography can be carried out in the usual manner through the common carotid artery.

The method of partial carotid occlusion outlined in this paper has not been put into practice because, since this experimental work was done, the author has not encountered a patient who would not tolerate complete carotid occlusion by the traditional methods. It is presented here for the consideration of other surgeons who may have such a patient under their care. It is to such a patient that this procedure should be restricted until the efficacy of this method stands the test of long-term follow-up. Then it is possible that this method may replace complete carotid ligation for other categories of patients.

SUMMARY

A rational basis has been established for the efficacy of carotid ligation in the treatment of intracranial internal carotid aneurysms. Experimental evidence is presented to demonstrate the role of partial occlusion of an artery in changing pulsatile to non-pulsatile intra-arterial flow without significant diminution in mean blood flow. A method of partial carotid occlusion is outlined as an alternative to carotid ligation in the treatment of certain intracranial aneurysms. The consequent elimination of pulsation is believed to protect the aneurysm from rupture. Further, the advantages of partial occlusion over complete ligation are considered.

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PAGES OUT OF THE PAST: FROM THE JOURNAL OF FIFTY YEARS AGO

A TREATISE ON DISEASES OF THE HAIR

This is a very large book upon a very small, though not unimportant subject, and the author descends into unnecessary minutiae. We cannot help thinking that many of his recommendations are counsels of perfection. For example, "If a woman's hair is scanty it is better for her to cut it short . . . than by wearing false braids to assume a beauty which she has not"; for a boy "it would be better to endure the down for a time as the growth of an elegant soft beard would be the reward". To demand that "the barber should refuse to work on any one who has any skin disease unless he is sure that it is not contagious" is attributing to barbers a degree of rectitude and diagnostic skill which must surely be unusual.—Book review, *Canad. Med. Ass. J.*, **3**: 57, 1913.